Earth Contamination Free Sample Acquisition From An Earth Contaminated Spacecraft 2001 IEEE Aerospace Conference

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Abstract— The paper describes the first step in the feasibility demonstration of a novel low cost Mars Sample Return Sample Transfer Sequence (STS) that does not require cleaning and sterilization of the entire spacecraft. The proposed STS relies on ability to collect (and in the future deliver to Earth) Earth-contamination-free samples from a spacecraft that was cleaned only to the levels achieved on Pathfinder. The latter satisfied Planetary Protection Category IVa (PP IVa) requirements, typical for a landed spacecraft. Ability to sterilize or clean to sterility the entire spacecraft is a risky and poorly developed technology. The proposed sample collection approach relies on mechanical removal of the contaminated surface layer and collection of a clean sample from the cleared area. Verification procedures for this approach require probabilistic assessments of the sample contamination levels for a given level of surface contamination.

This paper describes work done to validate feasibility of the proposed STS for soil samples. The samples are collected inside a disposable cleaned and sterilized container that has been implanted in the soil, and the contaminated soil has been scraped from under it (see Fig. 1). This procedure leaves a nearly uncontaminated surface from which samples may be collected. Using this technique, contamination levels were reduced by at least a factor of $4 \cdot 10^{-8}$. For comparison, sterilization is typically defined as a six orders of magnitude reduction in microbial population. The factor $4 \cdot 10^{-8}$ means that if each viable organism permitted on a PP IVa spacecraft is deposited exclusively onto the immediate areas where sample will be collected, there is less than 1% probability that any of these organisms will be found in the collected samples.

Sample cleanliness can be improved past $4 \cdot 10^{-8}$ (the best sample had $3 \cdot 10^{-8}$). Contamination probability was measured by seeding the soil surface with a marker contaminant (~$2.2 \cdot 10^{8}$ particles/cm^2) and measuring the amount of the marker that was collected in the sample (~10-20 particles/cm^2). Some of the contaminants observed in the collected sample were not transported there from the soil surface but were, in fact, false readings due to the overall lab contamination. The latter was confirmed by collecting samples from surfaces that were not seeded with marker contaminant. This background contamination is not a possible mechanism for the STS failure.

Decontamination-through-surface-removal techniques can be applied to samples other than soils. Several collection techniques for rocks based on the same abrasion principle have been identified. Feasibility demonstration of rock sample collection is a part of the FY'01 plans.

1. Introduction

PP Category V restricted return missions require the samples returned to Earth to be free from Earth originated biological contamination. These Earth originated roundtrip organisms do not represent any threat to Earth. However, it is very hard to prove that they did not come from Mars (false positive). Under these circumstances, the PP requirements would make nearly impossible the eventual release of the unsterilized returned samples from confinement.

Earth originated sample contaminants would be carried to the extraterrestrial venue by the lander and/or rover and spread to the soil surface where the sample is collected. In the past (Viking), this scenario was prevented by extreme measures undertaken to remove all biological material. The whole spacecraft was heat treated at 125C to achieve sterilization (or, more precisely, what was considered sterilization at the time). This cleaning process is strenuous, expensive, and often incompatible with the instrument design. Sample collection without the necessity of cleaning the entire lander and rover would be extremely advantageous. This report describes one such technique that permits collection of clean regolith samples from a spacecraft that is not cleaned to sterility.

2. Background

The proposed novel STS architecture has three major features:

- No part of the spacecraft that does not directly touch the samples is cleaned better than it is required to satisfy the Planetary Protection Category IVa requirements (Pathfinder clean).
- The samples collected and delivered to Earth are free of

the Earth-originated biocontamination with probability better than 99.9%.
- Biocontamination free state of the samples can be verified regardless of one's ability to detect every possible Earth life form.

The removal of the Category-IVb-like requirements from these elements should lead to significant cost savings. The technology for cleaning to sterility has not been developed to high Technology Readiness (TRL) level. In addition, some of the sub-system cannot be brought to this level of cleanliness without sacrificing performance within current budgetary constraints.

Contamination probability is calculated and verified not by measuring the number of bacteria, spore etc. found in the collection tools but by modeling soil and rock mechanics and measuring distribution of non-biological markers after sample collection.

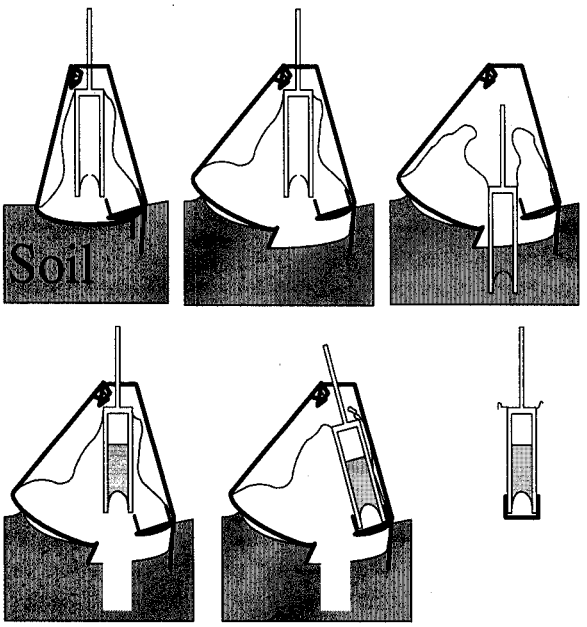

Figure 1. Sequence of steps to procure Earth-contamination free sample using a collection tool placed inside a device that is clean on the inside but contaminated on the outside.

Soil sample collection that satisfies these requirements may be performed in the following steps (see Fig. 1):

- The surfaces that will touch the sample are cleaned to the levels below the modern detection levels. These elements are wrapped in bioblanket (most probably, metallic foil). These disposable elements in their bioblanket wrappers are mounted on the rover. All the sub-systems outside of the bioblankets, including the bioblankets themselves, are at Category IVa cleanliness levels.
- On Mars, the bioblanket with the collection tools inside is placed against the surface so that it isolates a small area of the Marian soil. The scraper of the collection device is moved along the surface. The surface layer of the rock/soil is removed while the surface is still covered by the bioblanket. During the initiation of scraping the foil blanket under the scraper is torn apart.
- The sample is collected in the area under the bioblanket and the collection element is sealed with a lid while it is still under the bioblanket. These lids have to be designed impenetrable to the Earth organisms only. The latter is a well-established art. The seals do not need to be impenetrable to the possible Martian life or contaminants.
- The bioblanket is thrown away and the sample in its collection element with the lid in place is deposited into the sample cache. At this point, the collection elements may be handled with Earth-contaminated manipulators. The cache and the manipulators do not have to be cleaned to better than Category IVa levels.

The samples collected in the prescribed manner will be exposed only to the metallic foil bioblanket cleaned to the best level that the pre-launch technology will allow. The Earth-contamination-free state of the sample is guaranteed by design that can be tested on Earth. Table 1 compares the conventional architecture and the proposed one.

Within the current work no attempt was made to perform sterilization of the collection device or, even, design a flight worthy collection device. Only the feasibility of using a mechanical scraper to reduce contamination levels has been investigated.

1. Test Apparatus and Materials

The experimental fixture that emulated the surface removal part of the proposed sampler is described in Fig.2. The wedge shaped internal sterile volume bounded on one side by the scraper and on the other side by the back wall. The end surfaces of the wedge extend beyond the wedge and form the sidewalls. The container would be implanted in the soil with the wedge's pointed end downwards. The back wall and two sidewalls would be pressed into the soil, sealing out contamination on those sides. Upon actuation, the side of the wedge formed by the scraper would pivot about the top edge in the direction of the opening opposite the back wall, scraping the surface soil out of the opening and turning into the fourth side of a sterile box within which the sample is taken. There would be seals or bellows between the scraper and the sidewalls. The back wall should extend into the soil far enough to provide adequate reaction of the scraper actuation the top of the sample is not exposed to possible contamination. Note that the position of the scraper is adjustable. The apparatus allowed both rotary motion, as described above, and linear motion. In the linear motion mode, the scraper was moved to a vertical position with the pivot screws, that secured it in the rotary mode,

positioned above the top of the sidewalls. This maintains the scraper at a uniform depth. The whole assembly was held firmly in place with respect to the soil by additional structure.

In initial tests a Plexiglas sidewall, cat-box filler soil, and chalk contaminant, were used to observe soil, scraper, stone, and crust dynamics. However, in the interests of more accurate simulations during contamination tests, a Martian soil simulant was used. The Martian simulants are from a dissertation by Jeff Moore at Arizona State University and prepared by J. Green. Lunar soil simulant was similar to the texture of the Martian simulant and was used for some of the less critical contamination testing due to a Martian simulant shortage.

Eight-micron diameter dry Magnaflux particles were used to simulate biological contamination. They fluoresce yellow-green, may be collected magnetically, and counted under the microscope. A predetermined amount of particles was placed on the soil surface. The number of particles was control by weight. Concentration levels in excess of $2 \cdot 10^8$ particles per square centimeters were used. The approximate simulant densities are 1.4 g/cc as compared to 1.6 g/cc for the Magnaflux particles so the Magnaflux particles did not sink through the simulant excessively. After the sample was collected, individual particles that remain in the sample were counted. Typically, two three dozen particles will be detected. Some of these particles came from the air in the lab as was demonstrated by the background contamination tests. No correction for background contamination was

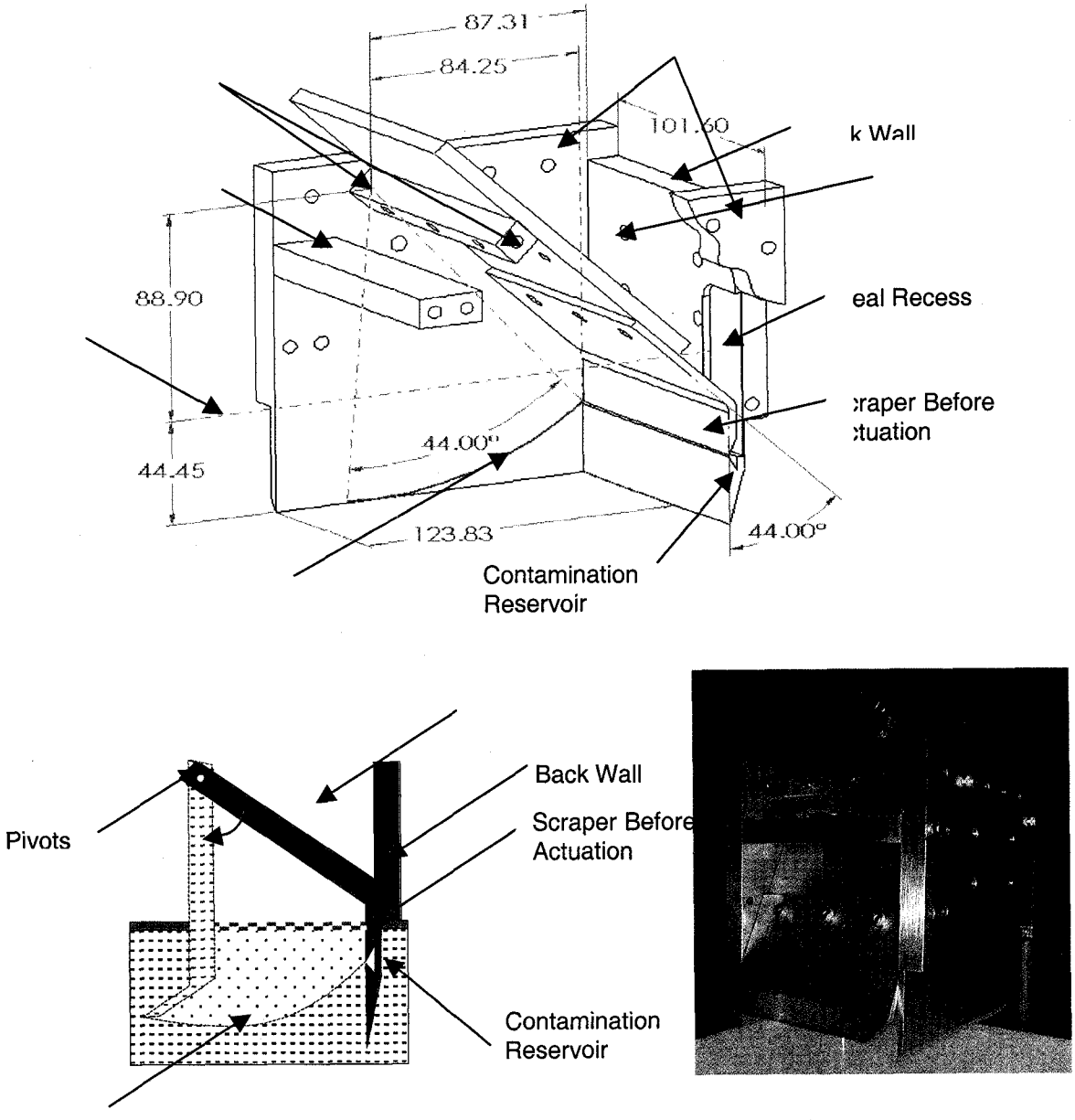

Figure 2. Test fixture used in the study

performed. The ratio of particles' concentrations before and after the test, was used as a measure of the contamination reduction

TEST PROCEDURES

Two types of tests have been performed within the scope of this study: soil recirculation tests and contamination tests

Recirculation Testing

Recirculation test were designed to eliminate the mechanisms through which the soil vortex in front of the scraper rotates in the direction opposite to that of the scraper motion and transport soil particles down along the scraper to the scraper tip. During this phase, the interaction dynamics of scraper configuration, soil, stones, and a soil crust were observed. Items 1 through 4 in the Results section were derived from these observations.

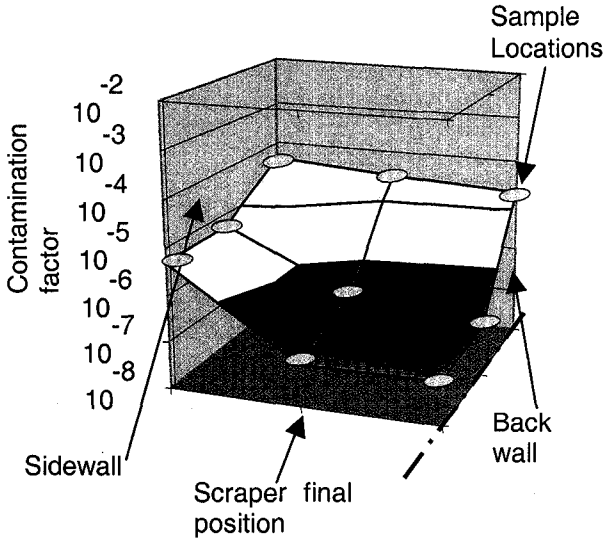

Figure 3. Contamination reduction factors for different locations within the scraped area. Only half of the area is shown. The distance between collection spots is 2.5 cm.

Contamination Tests.

These tests were conducted to demonstrate the effect of various parameters on contamination removal when the gross movement of the soil in front of the scraper moves soil particles away from the tip and to the surface. The test results were described by a contamination reduction factor or the probability that a particle on the soil surface will be detected in the collected sample. Seeding the soil surface with a marker contaminant and measuring the amount of the marker that was collected in the sample determined the reduction in contamination. The ratio of the surface contaminant concentration of the soil surface and the sample surface is reported as a contamination reduction factor.

The amounts of contamination remaining after scraping are so small (a dozen particles per square centimeter) that an incredibly small amount of external contamination will significantly alter results. The background contamination level was approximately 12 particles per collected typical $2cm^2$ sample. The latter corresponds to a contamination factor of around $3 \cdot 10^{-8}$.

In three tests, contamination was placed in one of three discrete locations to test their contributions to final contamination levels. 1) near the side-walls. 2) near the back wall. 3) in front of the middle of the scraper. Item 13 in the Results section is derived from these tests.

A series of tests were conducted with felt seals to reduce the contamination entry between the sidewalls and the scraper. Samples were taken at 9 locations and contamination factors are shown in Fig. 4. Item 14 in the Results section is derived from these tests. Note that even with felt seals, contamination near the sidewall was much greater than near the middle.

A test was conducted wherein a 20 mm. thick crust was created on the soil surface before implanting the apparatus. The crust had some cracks that allowed contamination easy access to lower soil levels. On Mars these cracks would probably be filled with dust or sand and not allow such easy access. The contamination factor for this test was 1.09E-07. Item 15 in the Results section is derived from this test.

RESULTS

Figure 3 represents typical results of a contamination test. Magnaflux particle concentrations were calculated for 9 samples. The contamination factors were calculated as a ratio of the initial contaminant concentration and the final one. The scraper was moving parallel to the page surface in the direction of the observer. The following are the major conclusions of the collection study:

1. Stones that are subject to either of the following two criteria are not thought to present a contamination problem:
   - Do not closely approach or penetrate the soil surface
   - Are located such that their center of resistance to motion through the soil is above the scraper tip. If stones do not approach or penetrate the surface, then they do not pull surface contamination into the soil if they roll during actuation. If stones center of resistance is above the scraper tip, they do not roll. They perform much as a volume of soil from a contamination standpoint.

2. Crust thicknesses less than half the initial scraper

implanting depth are not considered a contamination problem. The scraper tip is still submerged in loose soil under the crust. Contamination is prevented from falling down near it if a crust fragment turns on edge and dumps its load of contamination in front of the scraper during actuation. Crust thicknesses greater than the max scraper depth are not considered a contamination problem since they crush and become the same as homogeneous soil during actuation.

3. If the apparatus cannot be implanted very vertically, it is best to have it moving slightly towards the back wall as it is implanted. This will cause the back wall tip to remove some of the surface contamination that the scraper tip will have to penetrate before implanting. Moving the away from the back wall during implanting will collect additional contamination for the scraper to penetrate during implanting.
4. A positive rake angle causes the soil to move upwards along the scraper as it is actuated, carrying any contaminant away from the scraper tip where it might be smeared over the scraped area.
5. The 100 mm. wide scraper used in the testing (see Fig. 1.) required an actuation torque of 24 inch-lbs. when no stones were present.
6. This study indicates that the technique is feasible. Surface contamination reductions to 4.2×10^{-8} were seen using a scraper without seals similar to Fig. 1. If all 300,000 viable bacteria allowed on a Category IV-A vehicle were to fall in a single sample area before implantation and cleaning, there would be about 1 sample in 80 with bacteria in it after scraping. On the other hand, if a single bacterium were to fall in a single sample area before implantation and cleaning, there would be about 1 sample in 23 million with a bacterium in it after scraping.
7. As long as the rake angle was greater than zero, it had little to do with contamination removal.
8. Scraper curvature radius had little to do with contamination removal.
9. The deeper the scraper tip penetrates the soil, the better the contamination reduction was.
10. Scraper tip radius had little contamination removal as long as it was less than about .025 mm. This minimum size is probably related to the average soil particle size

11. The scraper must be recessed completely within the back wall. Contamination caught on or near the scraper tip during implanting is one of the major sources of contamination of the scraped surface.
12. The back wall should be as thin and tapered as possible to produce a sharp cut upon implanting and dragging as little contamination down to be distributed along the front face of the scraper/back wall where it can be smeared over the scraped area. To help alleviate this problem, a reservoir (see Fig. 1.) was built into the back wall so that the contaminant falls away from the tip of the recessed scraper when implanted.
13. Without seals, contamination passing between the scraper and sidewalls is the major source of contamination. The second greatest contamination source is that which gets on the scraper tip during implanting and is smeared on the scraped area.
14. The scraper must be at least 60 mm. wide and scrape at least 80 mm. linearly if seals comparable to ones used in this research are incorporated.
15. The presence of a crust can make the contamination factor worse by an order of magnitude due to entry through cracks. A deeper soil surface penetrating scraper will reduce this effect and improve overall performance.

CONCLUSIONS

Mission architectures that do not require total spacecraft sterilization for biologically clean sample collection are feasible.

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